DRILLING AND BLASTING, OPEN-CUT IRON-ORE MINES LAKE SUPERIOR DISTRICT

BY JOHN A. JOHNSON, FLOYD G. ANDERSON, AND ROY G. STOTT

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INTRODUCTION

This information circular discusses drilling and blasting in open-cut iron-ore mines and is one of a series of papers describing iron-ore mining practices in the Lake Superior district to aid in preventing accidents in that industry.

The Lake Superior district consists of the Marquette and Menominee ranges of Michigan, the Gogebic range of Michigan and Wisconsin, and the Vermilion, Mesabi, and Cuyuna range of Minnesota. Open-cut mines produce 80 percent of the iron ore mined in the district; 98 percent of the total Lake Superior district open-cut ore is produced in Minnesota and 2 percent in Michigan. The entire Wisconsin iron-ore production is from underground mines. The Mesabi range in Minnesota produced 93 percent of the open-cut iron ore and 76 percent of the total iron ore in the district in 1947.

During the 8-year period 1940-47, 619,000,000 gross tons of iron ore were shipped from mines of the district, or 85 percent of the United States output. Approximately 78,000,000 gross tons of iron ore were shipped from the mines of Minnesota, Michigan, and Wisconsin in 1947.

SCOPE

This paper is based primarily on observations during the period July 1947 to March 1948. Thirty-two open-cut mines were visited; 28 on the Mesabi range, 3 on the Cuyuna range, and 1 on the Marquette range. In 1947, 36,100,000 tons of iron ore was shipped from these 32 mines, or 59 percent of the open-cut ore and 46 percent of the total iron ore shipped from the district. During 1947 about 90 open-cut iron-ore mines were operating in the district, and the annual production of each ranged from 25,000 to 10,000,000 tons.

Many recommendations included in this paper for improving safety and preventing injuries to employees were taken from Bureau of Mines Information Circular 7387.

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- Oliver Iron Mining Co.
- Pacific Isle Mining Co.
- Republic Steel Corp.
- Rhude & Fryberger
- Snyder Mining Co.

GENERAL INFORMATION

Ore Bodies

All the Lake Superior iron ores occur in bedded formations that range from less than 100 feet to over 2,000 feet in thickness. These formations are designated by one commonly applied name, "iron formations."[4]

The Mesabi range in northern Minnesota, about 70 miles northwest of Duluth, was opened to mining in 1892; it is the largest single source of iron ore in the United States. It is 75 miles long and, because of the gentle dip of the ore formation, it ranges in width from 1-1/2 to 3 miles.[5] The ore formation, which is nearly horizontal, has a maximum thickness of about 450 feet and is covered by a glacial drift that ranges from 10 to over 100 feet in thickness. Most of the ore is near the surface and adaptable to open-cut mining.

At other iron ranges in the Lake Superior district the iron formations are inclined at steeper angles, and some are folded and faulted. The iron formation on the Gogebic range dips 45° to 70°, and on the Menominee range dips 15° to 90°. Only a small part of iron formations such as these can be mined by open-cut methods.[6]

Size and Type of Mines

The depths of the 32 open-cut mines visited ranged from 45 to 450 feet. Three of the mines were less than 100 feet deep, 14 were 100 to 200 feet deep, 7 were 200 to 300 feet deep, 5 were 300 to 400 feet deep, and 3 were 400 to 450 feet deep. The average depth was 216 feet.

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[4] Royce, Stephen, Geology of the Iron Ranges, Lake Superior Iron Ores: The Lake Superior Iron Ore Association, 1938, p. 28.

[5] Gardner, E. D., and Mosier, McHenry, Open-Cut Metal Mining: Bureau of Mines Bull. 433, 1941, p. 28.

[6] Yaworski, N., and Kiessling, O. E., Technology, Employment, and Output Per Man in Iron Mining: Works Progress Administration National Research Project and United States Department of the Interior, Bureau of Mines, Rept. E-13, June 1940, p. 59.

The 32 mines ranged from 400 to 13,000 feet in length and 400 to 4,000 feet in width (figs. 1 and 2). The average length was 3,150 feet and the average width 1,700 feet.

Fifteen of the mines used truck and belt conveyor haulage, 11 used trucks only, 5 used steam rail haulage, and 1 utilized Diesel-electric rail haulage.

Ratio of Overburden to Ore

Some of the 32 mines have been in operation for many years and all stripping work has been completed; at a few mines only a small amount of stripping remains to be done. The 32 mines produced 36,100,000 tons of iron, and 25,000,000 cubic yards of overburden and waste were removed in 1947, a ratio of overburden to ore of 0.7 to 1.

Seasonal Operations

The open-cut iron-ore mines in the district have a short operating season because of the severe winters. Transportation of ore on the Great Lakes is stopped for about 5 months during the winter. One-fourth of the total iron ore shipped from the open-cut mines of Minnesota is concentrated ore, and the washing plants at the mines are closed during freezing weather.

At most of the mines visited stripping was done in fall and winter after the regular mining of ore had been stopped; however, at some of the mines stripping was done during the entire year.

Employment and Production

Approximately 4,700 men were employed at the 32 mines in 1947, the number of men employed per mine ranging from 21 to 750. During the regular mining season most of the mines operated on a three-shift basis 6 days per week; however, some of the mines were operated on a one- or two-shift basis.

The 32 mines shipped 36,100,000 tons of iron ore in 1947. Seven mines shipped over 1,000,000 tons each, 13 shipped 500,000 to 1,000,000 tons each, 9 shipped 100,000 to 500,000 tons each, 2 shipped 50,000 to 100,000 tons each, and 1 shipped less than 50,000 tons (see table 1).

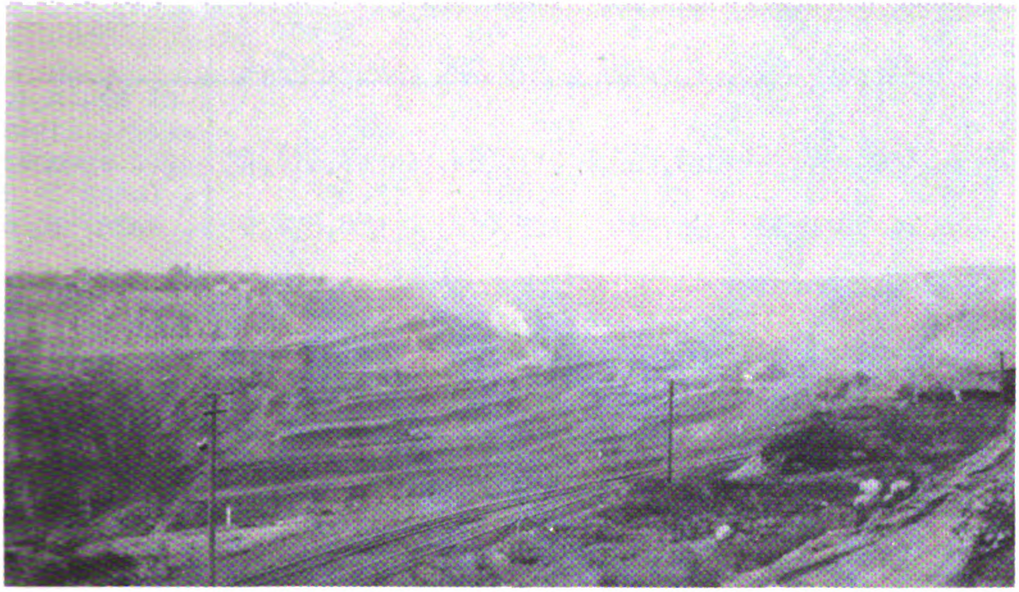

Figure 1. - General view of open-cut mine, showing rail haulage.

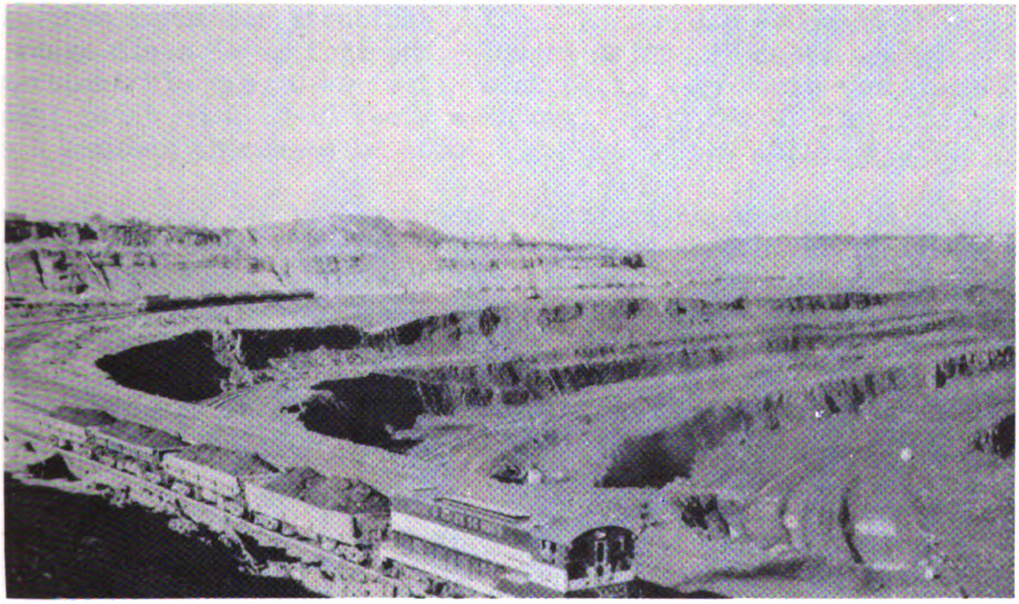

Figure 2. - Railroad approach to open-cut mine.

TABLE 1. - Open-cut iron-ore mines grouped as to annual production, Lake Superior district, 1947

	Over 1,000,000	1,000,000 to 500,000	500,000 to 100,000	100,000 to 50,000	50,000 to 25,000	Total
Open-cut mines in district	14	25	31	11	7	88
Total tonnage	34,676,443	17,487,779	8,283,816	729,853	208,445	61,386,336
Percent of total .	56.5	28.5	13.5	1.2	0.3	
Average per mine .	2,476,889	699,511	267,220	66,350	29,778	697,572
Mines in this study	7	13	9	2	1	32
Total tonnage	23,504,653	9,615,481	2,790,588	142,425	31,013	36,084,160
Percent of total .	65.1	26.6	7.7	0.4	0.1	
Average per mine .	3,357,808	739,652	310,065	71,213	31,013	1,127,630

DRILLING

Nature of Material

The ore usually is covered with glacial drift ranging in thickness from 10 to 130 feet, which can be mined with power shovels alone, except in the winter months when the top crust is frozen. At some mines the ore lies directly beneath the glacial drift, whereas at a few mines a layer of taconite 10 to 100 feet thick may separate the glacial drift from the ore.

The iron formation structure[7] from the surface downward at one of the Mesabi range mines is as follows: Glacial drift, 35 feet; taconite, 0-40 feet; merchantable ore, 0-40 feet; paint rock, 5-15 feet; merchantable ore, 5-15 feet; paint rock, 5-15 feet; wash ore, 25-30 feet. The iron formation attains a maximum thickness of about 450 feet on the Mesabi range.

Generally, the ore in the mines visited on the Mesabi range was mainly soft hematite and some limonite. In some mines very little drilling and blasting was necessary in the soft ore; however, loosening of the ore by blasting before loading was a general practice to reduce the loading time and to eliminate much "wear and tear" on the shovels.

At one mine in Michigan the ore was hard and abrasive, which made it difficult to drill and break, and all ore was drilled and blasted before loading.

Type of Drills

Vertical

With a few exceptions, vertical blast holes were drilled with standard caterpillar-mounted churn drills. Three-fourths of the number of churn drills were operated by 440-volt alternating-current motors and one-fourth were operated by gasoline-powered engines.

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[7] Gardner, E. D., and Mosier, McHenry, Work cited in footnote 6.

Six-inch chisel-type bits (concave, convex, and straight-edge) generally were used for drilling holes in ore, and at several mines 9-inch bits were used for drilling holes in hard ore and rock. At two mines a straight-edged bit with a 1- to 1-1/2-inch diameter depression in the center of the cutting edge was used. One driller stated that he obtained more footage per shift with a 9-inch drill bit than with a 6-inch bit in the same material.

Steel wire ropes were used for tool and sand lines. The tool lines were 3/4-inch left lay, and the sand lines were 3/8-inch right lay.

Horizontal

Horizontal holes were drilled occasionally when it was not feasible to drill vertical holes, but, because of the inherent dangers of material falling from the banks, the former method seldom was used. At seven mines, auger-type drills were used for drilling horizontal holes. At six of these mines, gasoline-driven drills with 6-inch diameter rotating augers were used, and at one mine a compressed-air driven drill with a 3-1/4-inch auger was used.

At two mines compressed-air operated, caterpillar-mounted, drifter-type rock drills were used to drill horizontal, inclined, and vertical holes in rock. These drills used 3-1/4- to 2-1/8-inch side-hole bits on 1-1/4-inch hollow round drill steel.

Guarding

Because many men were injured seriously while drilling in the past, operators of the open-cut mines in the district have provided more and better guards around the moving parts of drilling equipment.

The operators believe that the original equipment as received from the manufacturer has not been provided with adequate safeguards, and many operators installed additional guards before putting the drills into service.

With a few exceptions, most of the churn drills were provided with adequate sheet-metal guards (fig. 3) over moving parts. However, it was observed that sometimes guards were removed to make repairs and were not replaced after the repairs were completed.

One company operating a group of mines installed a metal screen fence around the working machinery of the drill; a gate in the fence provides access to the machinery. When the gate is opened the electric power to the drill is automatically cut off; the gate must be closed and a master switch thrown in before the drill can be operated.

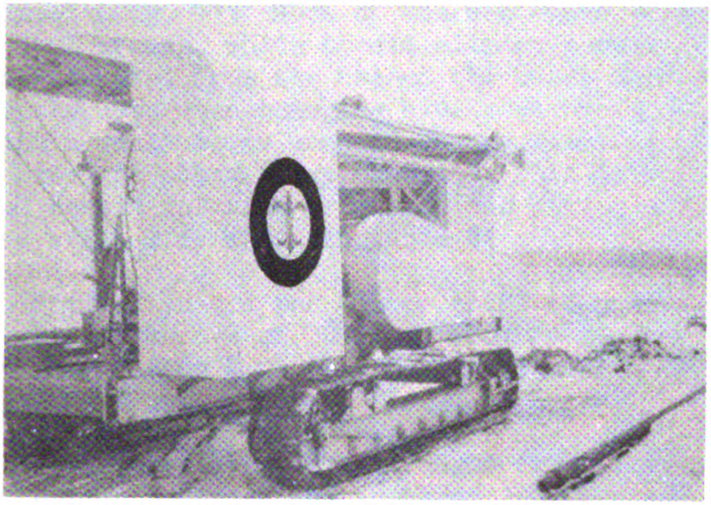

Figure 3. - Churn-drill guards and operator's shelter.

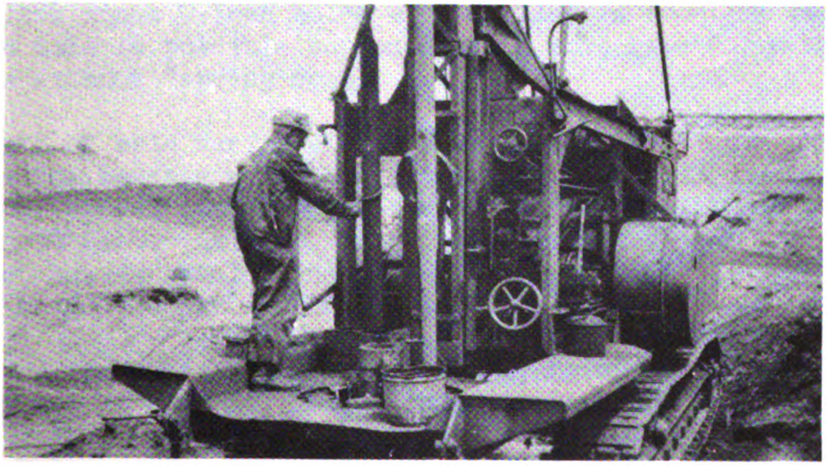

Figure 4. - Using hook to guide mud bailer on churn drill. Drill does not have operator's shelter.

Operation of Drills

Crews of two men, a driller and a helper, were employed on all drilling operations inspected. Most of the churn drills were equipped with a three-sided sheet-metal housing (fig. 3) on the front to serve as a shelter for the operator and helper in bad weather; however, a few drills were not so equipped (fig. 4). Most of the new churn drills were equipped with a new-type tool wrench, which should eliminate many of the accidents and injuries that resulted from the use of the heavy hand wrenches and chain tongs formerly used when changing bits. At one group of mines, a pick-up truck with a small hoist mounted on the rear was used for servicing the drills with bits and other heavy material; this device helps to avoid strained back and hernia injuries from handling bits. A summary of drilling data at the mines visited is shown in table 2.

The footage drilled in ore per 8-hour shift ranged from 8 in hard ore to 200 in soft ore, an average of 70 feet. The footage drilled in rock per 8-hour shift ranged from 4 feet in hard rock to 100 feet in medium rock, and averaged 40 feet.

The number of feet drilled per bit ranged from as low as 6 feet in hard ore to 300 feet in soft ore and averaged 120 feet per bit. Footage drilled per bit in rock ranged from as low as 2 feet in hard rock to 70 feet in medium rock and averaged 30 feet per bit.

Vertical Drill Holes

Virtually all churn-drill holes in ore were 6 inches in diameter; however, at six mines 9-inch holes were drilled in rock and hard ore. The 9-inch holes made it possible to concentrate more explosives at the bottom of the holes without "springing."

The depth of hole varied with the height of the bench, and as a general rule the benches were maintained at a height that could be trimmed with the power-shovel dipper. Holes ranged in depth from 10 to 60 feet and averaged 30 feet. At most mines the maximum depth of the holes was 35 to 40 feet but in special instances holes were drilled to a maximum depth of 50 to 60 feet at six of the mines.

At six of the mines using rail haulage, holes were drilled 3 to 5 feet below grade, and at one rail-haulage mine, holes were drilled 5 to 8 feet below grade. At about half of the truck-haulage mines, holes were drilled 2 to 5 feet below grade, but at several truck-haulage mines drilling was to grade only. Drilling below grade has its advantages in hard material, especially in rail-haulage mines, because it is easier to keep the floor on grade; however, in truck-haulage mines having soft ore a more solid floor is maintained for the shovels and trucks when drilling is to grade only.

TABLE 2. - Drilling practice at open-cut iron-ore mines

	Kind of drill				Drill holes							
								Spacing, feet		Feet drilled		
Mine	Vertical	Horizontal	Kind of power	Type of bit	Diameter, inches	Depth drilled, feet	Depth drilled below grade, feet	In rows	Of rows	Per bit	In 8 hrs.	Material drilled
1	Churn		Electric	Chisel	6	30-50	-	30-50	25	70-90	80	Ore, soft-medium.
	do.		do.			35	-	20	20	-	40	Rock, medium.
		Auger	Gasoline	Auger	6	40	-	30	-	150-200	150-200	Limonite, ore.
2	do.		do.	Chisel	6	30-50	-	16	16	200	100-200	Ore, soft-medium.
	do.		do.	do.	6	30-50	-	16	16	-	15-100	Rock, medium.
		Auger	do.	Auger	6	30	-	25	-	50	120	Ore, medium.
3	do.		Electric	Chisel	6	15-35	2	10-20	13	60-70	150	Do.
	do.		do.	do.	6	15-35	2	10-20	13	25-30	3-4	Rock, hard.
4	do.		do.	do.	6	15-30	-	15-20	15-18	200-300	100	Ore, soft.
	do.		do.	do.	6	15-30	3-5	10-20	10-20	45-50	15	Ore, hard.
5	do.		do.	do.	6	20-35	-	30	30	200	60-150	Ore, soft.
	do.		do.	do.	6	20-35	-	15-27	15-27	10-40	15-50	Rock, medium.
6	do.		do.	do.	6	18-60	4-5	18-60	-	20-120	8-120	Ore, soft-hard.
		Auger	Gasoline	Auger	6	34	-	18	-	35	125-150	Ore, soft-medium.
7	do.		Electric	Chisel	6	30-50	5	30-35	30-35	50-150	200	Ore, soft-hard.
	do.		do.	do.	9	30-35	5	20	20	5-25	20-50	Rock, medium.
		Auger	Gasoline	Auger	6	25-30	-	18-20	-	30-50	250	Ore, medium.
8	do.		Electric	Chisel	6	25-40	5	18-30	20	100	80-100	Do.
	do.		do.	do.	6	25-40	5	18-30	20	3-20	15-40	Rock.
9	do.		do.	do.	6	20	5	20	20	40	80	Ore, soft-medium.
10	do.		do.	do.	6	30	5	25	25	100-200	90-170	Do.
	do.		do.	do.	9	32	5	16-22	16-22	7-8	30	Rock.
11	do.		do.	do.	6	20-35	5	18	18	80-120	80-120	Ore, soft-hard.
	do.		do.	do.	9	20-35	3	15-18	15-18	5-10	16-30	Rock, hard.
12	do.		Gasoline	do.	6	15-20	3-5	12-15	12-15	200	100-200	Ore, medium-hard.
	do.		do.	do.	6	15-20	3-5	12-15	12-15	30	15-35	Rock.
13	do.		Electric	do.	6	25-35	3-5	15-20	100-200	80-150	80-150	Ore, medium-hard.
	do.		do.	do.	6	25-35	3-5	15-20	15-20	50	50	Rock, hard.
14	do.		do.	do.	6 & 9	20-40	5	20-30	18	100-300	40-100	Ore, medium.
	do.		do.	do.	6 & 9	20-40	5	18-24	18	2-15	12-40	Rock, medium-hard.
15	do.		do.	do.	6	10	5	10	10		40-50	Rock
16	do.		do.	do.	6	30	5	12-17	12-17	100-125	50	Ore, medium.
17	do.		do.	do.	6	40	0	17-25	17-20	50-100	40-50	Ore, soft.
18	do.		do.	do.	6 & 9	30	3	12-18	12-18	40-80	40	Taconite.
		Gopher	Gasoline	Auger	6	27-35	-	25	-	30	140	Ore, soft.
19	do.		do.	Chisel	6	20	-	20-30	20-30	40	40	Do.
20	do.		Electric	do.	6	25	-	20-25	15-20	250	125	Do.
	do.		do.	do.	6	30	5	12-14	5-16	-	-	Ore and rock, mixed.
21	do.		do.	do.	6	32-40	5-8	15-20	10-15	5-10	21-30	Hard siliceous ore.
22	do.		do.	do.	6	25	5	20-35	15-25	6-60	30-90	Ore, soft-hard.
23	do.		Gasoline	do.	6	10-25	5	12-20	12-20	300	75-110	Ore, soft-medium.
		Auger	do.	Auger	6	36	-	20	-	144-216	144	Ore, soft.
24	do.		do.	Chisel	6	12-14	-	12-25	12	10-20	40-50	Rocky wash ore.
25		Sinker	Comp. air	Auger	1-1/2	8-12	-	-	-	-	-	Seams of sand or ore in rock.
26	do.		Gasoline	Chisel	6	10	-	20-25	-	60-80	60-80	Hard pan.
27	do.		Electric	do.	6	16-20	5	12-20	15	140	25-30	Ore, soft-hard.
28	do.		do.	do.	6	38-50	-	21	21	30-60	20-80	Paint rock.
29	do.		do.	do.	6-1/4	35	5	12-14	-	50-150	100-150	Rocky iron ore.
		Drifter	Comp. air	Cross	3-1/4	12	-	15	-	-	600	Rock.
30	do.		Gasoline	Chisel	6-1/4	12	-	12	-	50-100	60-100	Taconite.
		Drifter	Comp. air	Cross	3-1/4	6	-	6	-	-	600	Do.
31	do.		Electric	Chisel	9	30-35	5	24	30	-	80	Rock, soft-hard.

At most mines, churn-drill holes for blasting in ore were spaced at intervals equal to the height of the bench; however, at some mines the interval between holes was three-fourths of the depth of the holes, and at others it was two-thirds of the depth. At one hard-ore mine the interval between holes in ore was one-half the depth of the holes. The interval between churn-drill holes in rock was usually two-thirds the depth of the holes.

For shallow holes the interval between rows of holes generally was the same as the interval between holes in individual rows; for deeper holes the interval between rows was either three-fourths or two-thirds of the interval between holes.

Generally, churn-drill holes were loaded for blasting soon after they were drilled, to prevent blocking of holes in soft material. At a few mines, hay or a wooden plug was used to keep the holes open until they were loaded. At one group of mines, a wooden cover 2 feet square, with a galvanized-iron top, was placed over all vertical holes by the drill crew to prevent material from falling into the holes and to prevent men from stepping into them.

Horizontal Drill Holes

Six-inch horizontal blast holes in soft ore were drilled with auger-type drills at three mines. The holes were spaced 18 to 25 feet apart and were drilled to a depth of 27 to 36 feet at a slight angle below horizontal. The footage drilled per 8-hour shift ranged from 125 to 150 feet, and footage per bit ranged from 30 to 200 feet. At one mine an isolated island of wash ore (about 300 feet long, 100 feet wide, and 30 feet high) in the center of the pit had to be mined by drilling horizontal blast holes, because churn drills could not be moved to the top of the island for vertical drilling.

At three mines, 3-1/4-inch horizontal holes were drilled in rock and rocky ore with pneumatic drifters using cross-type bits. Holes were spaced 6 to 15 feet apart and were drilled 6 to 12 feet deep. As many as 100 6-foot holes were drilled in an 8-hour shift.

STORING AND HANDLING EXPLOSIVES

Delivery

Supplies of explosives, detonators, safety fuse, and detonating fuse were delivered by the manufacturers to the mines as requested on 24-hours notice, consequently deliveries of large amounts at one time were not necessary. The manufacturers' trucks delivered the explosives to the mine magazines outside the pits, to magazines in the pits, to railroad-car magazines, or, at times, directly to blasting sites. The amount of explosives delivered to a single magazine ranged from 1,000 to 15,000 pounds, depending on the size of the operation.

Storage

With a few exceptions, the explosives-storage magazines at the open-cut mines were substantial, sheet-steel, sectional-type, portable magazines sold by explosives manufacturers. These magazines ranged in size from 6 feet wide, 6 feet long, and 7 feet high, and a recommended capacity of about 6,000 pounds of explosives, to 10 feet wide, 20 feet long, and 9 feet high, and a recommended capacity of about 40,000 pounds (figs. 5 and 6).

Detonators were stored in sheet-metal, sectional-type, portable magazines situated a safe distance from the explosives-storage magazines either on top of the pit or in the pit. At some mines where only a small number of detonators were stored, a wooden box painted red was used for storage in the warehouse.

Three of the rail-haulage mines had explosives-storage magazines mounted on railroad cars. These magazines were used to store explosives, and to haul explosives to blasting sites and to return unused explosives to safe storage locations. Figure 7 shows one of these magazines of steel and wood construction lined with wood. It is equipped with hand and standard air brakes, both of which can be applied from the car platform. The car has safety connecting chains and automatic couplings. The side door, which facilitates loading and unloading, is locked from the inside.

Transportation to Blast Locations

At most mines the explosives manufacturers' trucks delivered explosives to small, sheet-steel, sectional-type, portable, temporary storage magazines near the blasting sites, and the blasting crews carried the explosives from the magazine to the blast holes. When large blasts were to be set off, the manufacturers' trucks usually delivered the explosives directly to blasting sites.

At mines where the explosives-storage magazines were situated away from blasting operations, supplies of explosives were transported to blast holes in company-owned pick-up trucks at the start of the shift or as needed. Figure 8 shows a panel truck, with doors on the side and the rear, that was built for transporting explosives only.

Generally, the blaster carried the detonators from the detonator magazine to the blasting site in a small wooden box, but in some instances the detonators were placed in a small wooden box and transported on the seat of the explosives truck.

At many mines, a few 1-1/4- by 8-inch cartridges of dynamite were stored near each churn-drill in a 12- by 12- by 12-inch wood box painted red; a similar box was used to store a few electric detonators or a few capped fuses. Such blasting supplies were used for removing obstructions from churn-drill holes.

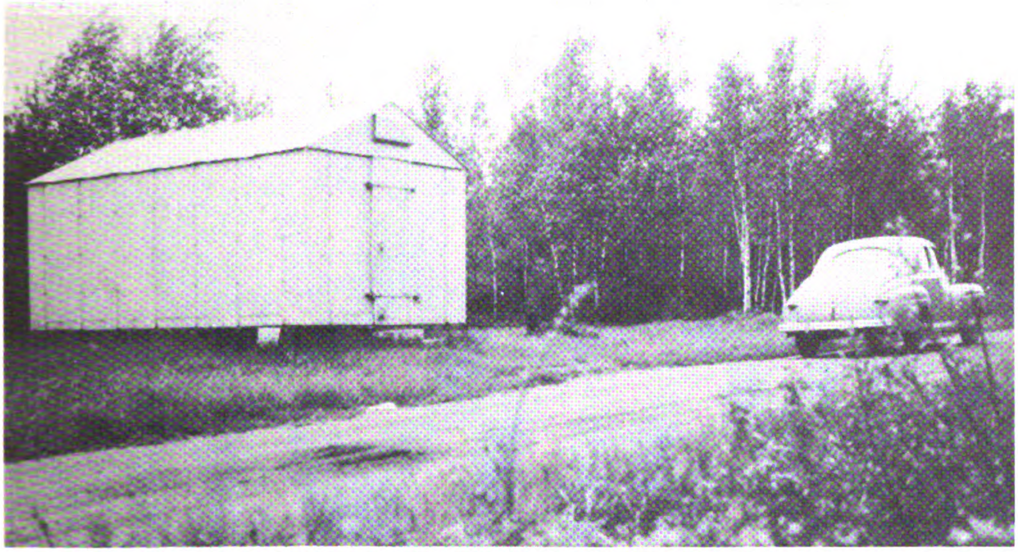

Figure 5. - Main explosives-storage magazine. Sheet-steel sectional-type lined with "flinkote."

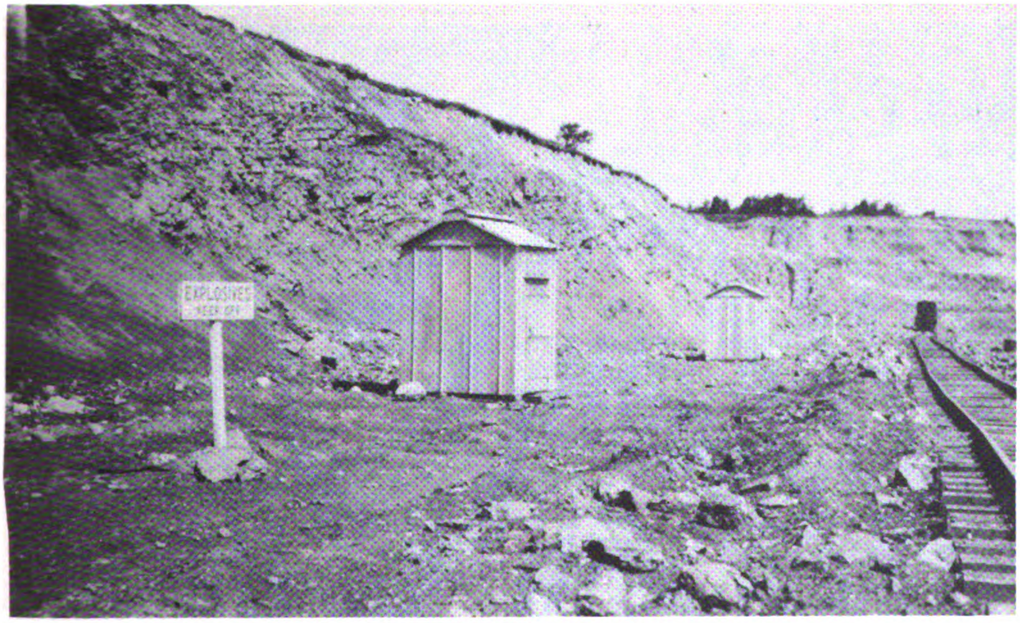

Figure 6. - Portable explosives-storage magazines in open-cut mines.

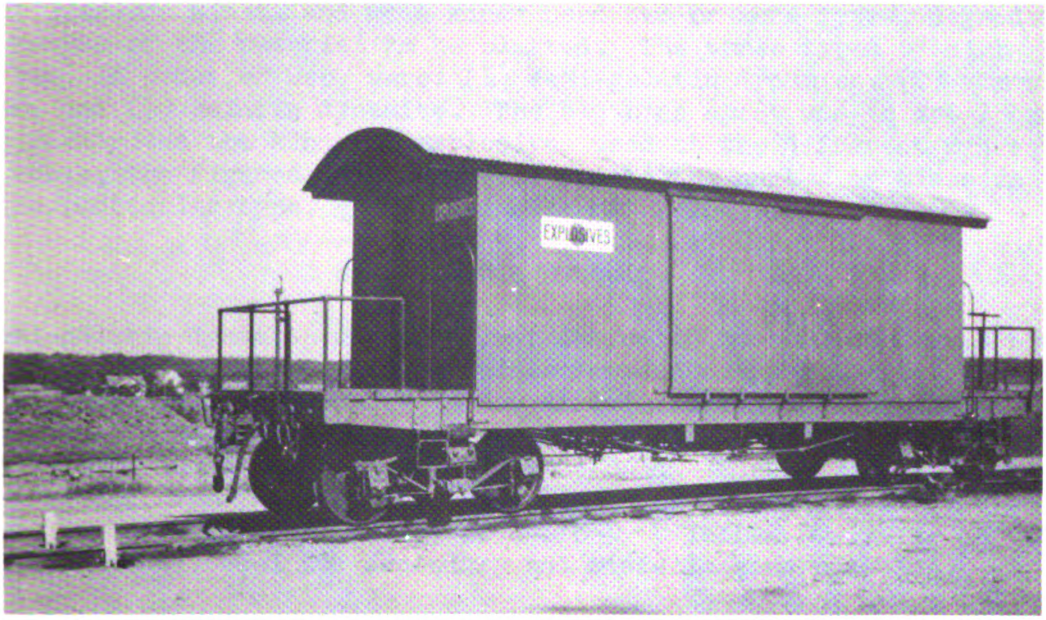

Figure 7. - Explosives car used in open-cut mines.

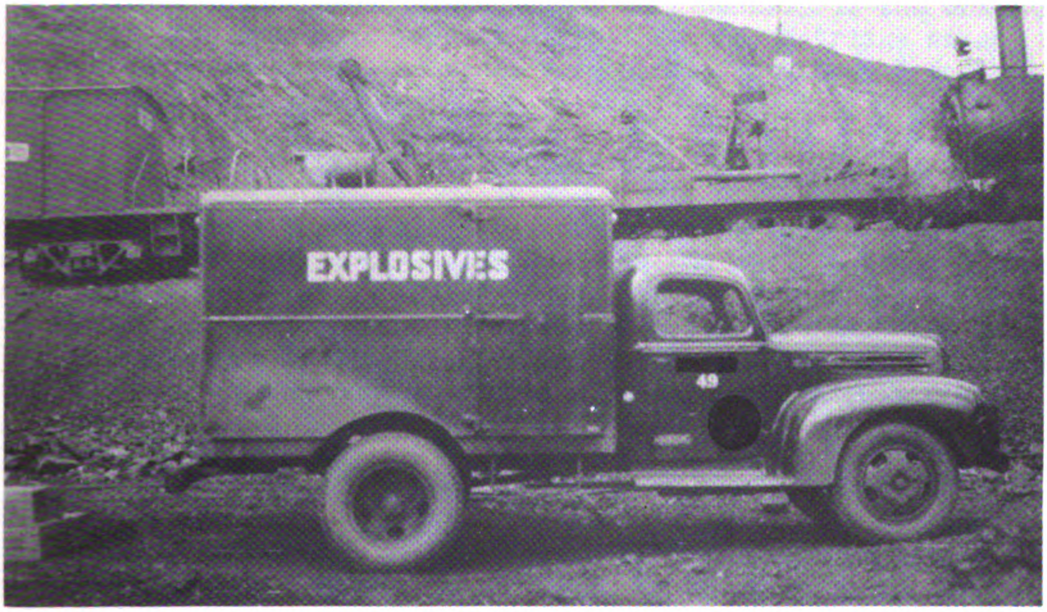

Figure 8. - Panel truck for transporting explosives to blasting site.

Blasting Supplies

Three types of high explosives and a blasting agent were used in the open-cut iron-ore mines, and most mines used two or more types, depending on the nature of the material to be blasted. The three types of high explosives, in order of use, were: (1) semi-gelatin dynamite, (2) ammonia dynamite, and (3) gelatin dynamite. The blasting agent was in metal cans. Table 3 summarizes the kinds of explosives used at the different mines; in the table, the figures in parenthesis denote the number of mines in which the particular type, grade, and size of explosives were used.

Semi-Gelatin Dynamite

Semi-gelatin dynamite was the first choice of most of the mines for primary blasting and of many of the mines for secondary and miscellaneous blasting. Semi-gelatin dynamite is not as water-resistant as gelatin dynamite but can be used in wet holes. Two grades of semi-gelatin dynamite (60 and 40 percent strength) generally were used. Cartridges ranged in size and weight from 7-1/2 by 24 inches (weighing 50 pounds each), used in 9-inch diameter churn-drill holes, to 1-1/8 by 8 inches (weighing about half a pound each), used for secondary and miscellaneous blasting.

Ammonia Dynamite

Ammonia dynamite was the second choice for primary blasting and also for secondary and miscellaneous blasting. The water resistance of the ammonia dynamites has been improved materially, and by the proper selection of grades they now can be used in wet holes, particularly if the wrapper is not removed. The grades in percent strengths, the cartridge sizes, and the cartridge weights used at the mines were similar to those described under semi-gelatin dynamite.

Ammonia Bag Dynamite

Ammonia bag dynamite generally consists of free-flowing powders packed in bags ranging in size from the 7-1/2 by 24 inches and weighing 50 pounds to 5 by 14 inches and weighing 12-1/2 pounds. This type of explosives has low water resistance and was used primarily in dry holes that were too ragged for satisfactory loading with cartridges or in small-diameter holes that were chambered at the bottom. It is a powerful but slow-acting dynamite.

Gelatin Dynamite

Gelatin dynamite was not used as extensively as other explosives because of its high cost; it was used only at a few mines, principally in extremely wet holes. This type of explosives is dense, plastic, and virtually waterproof. Two grades of gelatin dynamite were used - 25-percent strength in 5- by 16-inch and 3- by 10-inch cartridges for primary blasting, and 40-percent strength in 1-1/4- by 8-inch cartridges for secondary and miscellaneous blasting.

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TABLE 3. - Types of explosives used

Type of explosives	Primary blasting					Secondary blasting			
Gelatin dynamite				(8)	(5)		(1)		
Weight strength, percent				25	25		40		
Size of cartridge, inches				5x16	3x10		1-1/4x8		
Weight of cartridge, pounds				16.7	4.0		±0.5		
Semi-gelatin dynamite	(3)	(5)	(7)	(7)	(3)	(1)	(3)	(4)	
Weight strength, percent	60	60	40	60	60	40	60	60	
Size of cartridge, inches	7-1/2x24	5x24	5x24	5x16	3x10	2x12	1-1/4x8	1-1/8x8	
Weight of cartridge, pounds	50.0	25.0	25.0	16.7	4.0	±2.0	±0.5	±0.4	
Ammonia dynamite	(1)	(1)	(1)	(2)	(1)		(1)	(7)	(3)
Weight strength, percent	60	40	60	40	40		40	40	40
Size of cartridge, inches	7-1/2x24	7-1/2x24	5x14	5x14	3-1/2x10		1-1/4x8	1-1/8x8	7/8x8
Weight of cartridge, pounds	50.0	50.0	12.5	12.5	5.0		±0.5	±0.4	±0.3
Ammonia dynamite (bag)	(3)	(1)	(2)	(3)					
Weight strength, percent	65	65	65	40					
Size of bag, inches	7-1/2x24	5x22	4x24						
Weight of bag, pounds	50.0	16.7	12.5						
Blasting agent	(5)	(1)	(2)						
Weight strength, percent	75	50	40						
Size of can, inches	5-1/2x24	5-1/2x24	5-1/2x24						
Weight of can, pounds	27.5	22.0	25.0						
Specific gravity	1.33	1.06	1.21						

Note: - Figures in parenthesis denote the number of mines in which each type was used.

Blasting Agent

A blasting agent in 5-1/2- by 24-inch sealed metal cans was used at a few mines for blasting 6-inch churn-drill holes and coyote holes. The blasting agent is available in five grades ranging from 75 to 40 percent equivalent strength, and in cans ranging in diameter from 4 to 9 inches; however, only three grades, 75-, 50-, and 40-percent strength, in 5-1/2-inch diameter cans only were observed in use. The two highest grades have a specific gravity of 1.33 and 1.21, respectively, and can be used for blasting holes filled or partly filled with water. At one mine, ten 25-foot vertical holes containing about 10 feet of water were blasted successfully with this blasting agent. Extreme care was used in loading the holes to prevent lodgment of loose material between adjacent cans.

The manufacturer of the blasting agent states that it cannot be detonated by (1) blasting caps, (2) detonating fuse, (3) flame, (4) the impact of a rifle bullet, or (5) heavy steel weights such as a drill bit. Generally, it is detonated by a special primer consisting of T.N.T. in combination with other materials in a sealed metal can. However, a primer of suitable high explosives can be used for detonating purposes if certain specific practices are adhered to.

Detonating Fuse and Safety Fuse

Detonating fuse was used for blasting charges at 31 of the 32 mines; electric detonators with 24-foot leg wires were used for blasting all holes at the other mine. Generally, reinforced detonating fuse was used in the holes, and plain fuse was used for trunk lines on the surface of the ground. Most mines obtained detonating fuse on spools in 500-foot lengths, but a few mines obtained 1,000-foot lengths. Detonating fuse is insensitive and cannot be detonated by friction, ordinary shock, or a 30-caliber bullet; it generally is detonated by a blasting cap or an electric detonator tied or taped to its end. Detonating fuse has a velocity of detonation of 20,300 feet per second and explodes with enough violence to detonate a column of dynamite in a borehole alongside of it virtually instantaneously along its entire length. The almost universal use of detonating fuse for primary blasting in open-cut iron-ore mines in the Lake Superior district is one of the outstanding safety practices adopted in recent years.

At 11 of the 32 mines safety fuse and blasting caps were used to initiate the detonating fuse or in secondary and miscellaneous blasting. The nominal burning rate of the safety fuse was 40 seconds per foot. Fuses were cut and "capped" at the blasting sites at six mines, and at the operation detonator-storage magazines or boxes at five mines. Pocket knives were used to cut the fuse at eight mines and a combination fuse cutter and crimper was used at three mines. Capped fuses ranged in length from 14 inches to 5 feet; fuses 2 to 5 feet long were used at six mines, and at five mines fuses were 2 feet or less in length. The Bureau of Mines recommends that capped fuses less than 30 inches in length should not be used, because many serious blasting accidents in mining districts throughout the United States have been caused by the use of short fuse.

Detonators

Of the 32 mines, electric blasting was practiced at 21, cap and fuse were used at 5, both electric blasting and cap and fuse were used at 6. No. 6 strength detonators were used in all blasting.

Electric detonators with copper leg wires were used at most of the mines, but at a few mines detonators with enameled copper leg wires were used. Leg wires ranged in length from 6 to 40 feet; the most common lengths were 6, 12, 20, 24, and 30 feet. All electric detonators were purchased with shunted leg wires.

Instantaneous electric detonators only were used at 20 mines; instantaneous and first and second delays were used at 2 mines; instantaneous and first, second, and third delays were used at 4 mines; and instantaneous and first, second, third, and fourth delays were used at 1 mine.

Preparation of Primers

Primers were prepared immediately before use at the blasting site at all the mines. Wooden or copper punches were used for making holes in the large dynamite cartridges when preparing primers with detonating fuse. At a few mines the end of a hand-type cap crimper was used for punching holes in the smaller cartridges.

Primers With Cap and Fuse

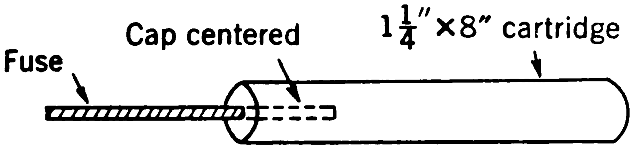
At only 2 of the 32 mines were the primers prepared with cap and fuse. At one mine the primer was prepared by punching a hole along the longitudinal axis from the center of one end of a 1-1/4- by 8-inch cartridge, after which the cap with fuse attached was inserted in the hole (fig. 9-A). The fuse was not tied to the cartridge. This primer was used when mud-capping large boulders.

Another primer, using a 3-inch length of a 3- by 10-inch cartridge, was prepared by punching a transverse hole halfway through the cartridge about 1 inch from one end. The cap was inserted in this hole, a second transverse hole was punched through the cartridge from one side an inch from the end, and the fuse was laced through the second hole and pulled tight (fig. 9-B). Such a primer was used in "springing" churn-drill holes.

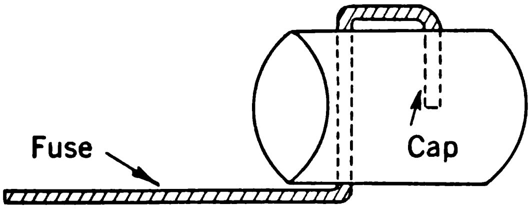
Primers with Electric Detonators

At 14 of the 32 mines, primers were prepared with electric detonators; at 1 mine primers with electric detonators were used for all blasting; and at 13 mines primers with electric detonators were used when cleaning and springing blast holes and in blasting large chunks with block holes.

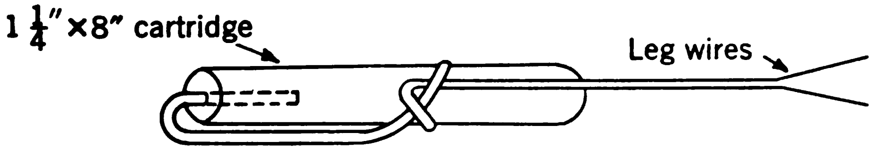
Three general types of primers were used. In the first type (fig. 9-C), a hole along the longitudinal axis was punched in the center of one end of the cartridge, the detonator was inserted in this hole, and the leg wires of the detonator were tied in a half hitch around the center of the cartridge.



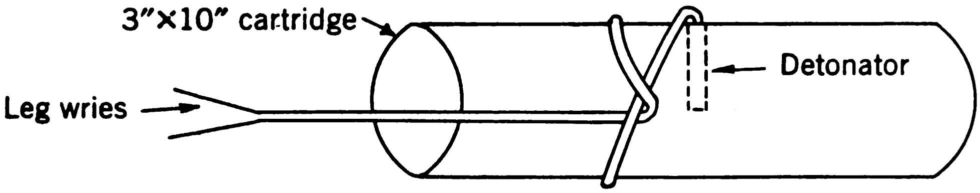
A. Center priming with cap and fuse, not tied with string.



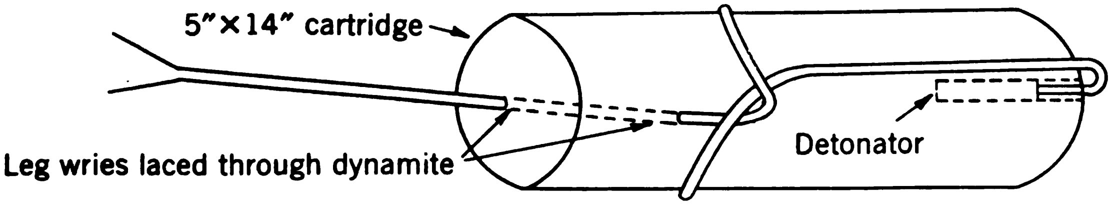
B. Side priming, lacing fuse in piece of 3"×10" cartridge.



C. Center priming with electric detonator, half hitch.

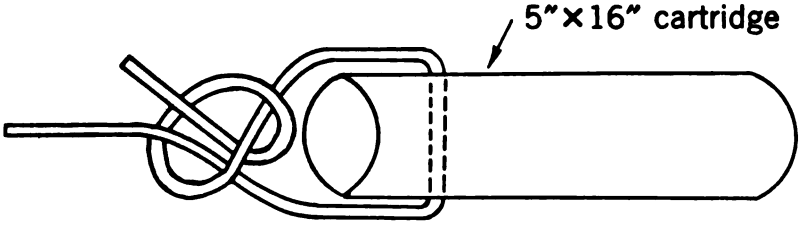


D. Side priming with electric detonator, half hitch.

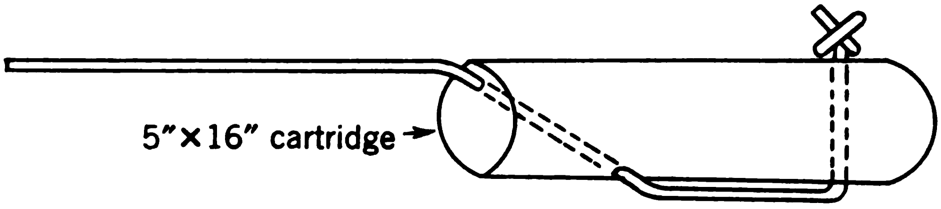


E. Side priming with electric detonator, half hitch and lacing.

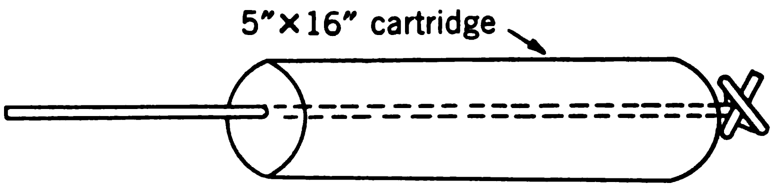
Figure 9. - Methods of preparing primers. A and B with cap and fuse; C, D, and E with electric detonators.



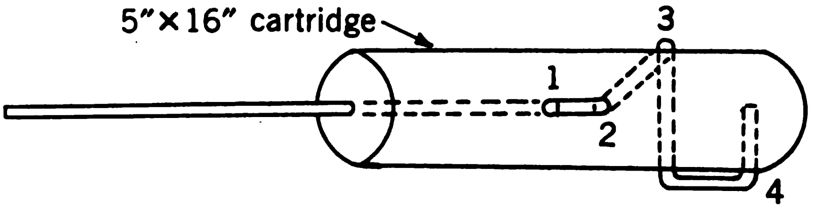
A. One threading with a slip knot in detonating fuse.



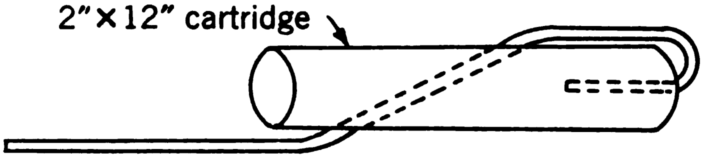
B. Two threadings with a plain knot in detonating fuse.



C. One threading with a plain knot in detonating fuse.



D. Four threadings without knot in detonating fuse.



E. Two threadings without knot in detonating fuse.

Figure 10. - Methods of preparing primers with detonating fuse.

A modification of this type of primer was obtained by tying the leg wires to the cartridge with two half hitches. In another modification, two electric detonators were inserted in separate holes in the same end of the cartridge, and two half hitches were tied around the cartridge with both sets of leg wires. In this modification, only one set of leg wires was connected to the blasting circuit; the second detonator was used only if the first detonator failed to fire the charge of explosives.

Figure 9-D illustrates the second type of electric primer. A transverse hole was punched near the center and halfway through a 3- by 10-inch cartridge. The detonator was inserted, and the leg wires were tied in a half hitch around the cartridge. Such a primer was used in springing holes.

In the third type (fig. 9-E), a 5- by 14-inch cartridge of dynamite was used. This primer was similar to the primer shown in figure 9-C, where the detonator was inserted in the end of the cartridge. A diagonal hole was punched in the cartridge as shown in figure 9-E, so that it pierced the side about 4 inches from the end. After a half-hitch was tied around the cartridge with the leg wires, they were threaded through this hole from the side, coming out the end. This primer was used for blasting all churn-drill holes at a mine where detonating fuse was not used.

Primers with Detonating Fuse

Five general types of primers with detonating fuse were used. Figure 10-A illustrates the type used at most mines. A hole was punched through the short axis of the dynamite cartridge about 3 inches from one end; the detonating fuse was threaded through the hole and tied on top with a slip knot.

In the second type of primer with detonating fuse (fig. 10-B) a diagonal hole was punched from one end of a cartridge near the side, piercing the opposite side of the cartridge near the midpoint, and a second hole was punched through the short axis of the cartridge about 3 inches from the opposite end. The fuse was threaded through the first hole, starting from the top of the cartridge, then through the second hole, and finally was tied in a single knot on the side, after which the fuse was pulled tight from the top.

Figure 10-C illustrates the third and simplest type of detonating-fuse primer. The fuse was threaded through a longitudinal hole in the cartridge and tied in a single knot at the other end of the cartridge.

The fourth type (fig. 10-D) was the most complicated primer with detonating fuse and was used at only one mine. Hole 1 was started from one end of a 5- by 16-inch cartridge near the side and pierced the opposite side near the midpoint of the cartridge; hole 2 was punched through the short axis in the same plane as hole 1 about 2 inches from the midpoint end of hole 1; hole 3 was punched through the short axis perpendicular to and about 2 inches away from hole 2; hole 4 was started 2 inches away from hole 3 in the same longitudinal plane and was punched halfway into the cartridge along the short axis. The fuse was threaded from the top of the cartridge through holes 1, 2, and 3 and inserted into hole 4, after which it was pulled tight from the top.

The fifth type of primer with detonating fuse was prepared with a 2- by 12-inch dynamite cartridge. A hole about 3 inches long parallel to the long axis was punched in the center of one end of the cartridge, and a second (diagonal) hole was started from the midpoint on one side and pierced the opposite side about 1 inch from the other end of the cartridge. The fuse was threaded through the diagonal hole from the top, then bent back and inserted into the hole in the bottom. The slack fuse was pulled tight at the top.

LOADING BLAST HOLES

Cleaning Vertical Holes

Generally, no cleaning of churn-drill holes was necessary except that done by bailing, as most holes were loaded promptly after drilling. If holes were obstructed before loading, they were cleaned by redrilling or by shooting with one or two sticks of dynamite.

Springing Vertical Holes

Springing or chambering drill holes was not a general practice; holes were sprung at 5 of the 32 mines in hard material only. Holes generally were sprung once with a charge of 4 to 15 pounds of dynamite; about two pails of water were used for stemming, and the charge was detonated either by an electric detonator or by cap and fuse.

At one mine, vertical blast holes in hard material were sprung three times. The first springing charge consisted of four cartridges of 1-1/8- by 8-inch, 60-percent, semi-gelatin dynamite to blow out mud and water; the second charge consisted of 10 cartridges (about 4 pounds), and the third charge consisted of 25 to 30 cartridges (10 to 12 pounds). All charges were fired electrically. The waiting period between springing charges was 1 to 2 hours, and a few pails of water were poured in to assist in cooling the holes. The temperature of a hole was tested by feeling the heat of a wooden charging stick after it was inserted in a sprung hole.

Loading Vertical Holes

Semi-gelatin dynamites, gelatin dynamites, or a blasting agent in sealed metal cans were used in wet holes, and ammonia dynamites in cartridges and bags were used in dry holes. All holes were tested with a tamping block or by observation with a mirror before loading to make sure they were not obstructed. At most mines, the cartridges of explosives were dropped into the holes, but at four mines the explosive cartridges were lowered into the holes (fig. 11). Explosives manufacturers recommend that cartridges of explosives be lowered into holes that are ragged. Where the blasting agent was used it was lowered into the holes.

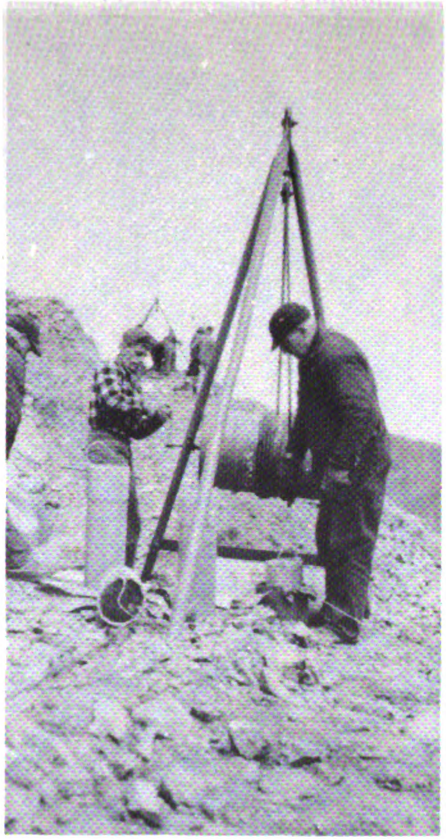


Figure 11. - Lowering 50-pound cartridge of explosives into a 9-inch churn-drill hole by means of tripod.

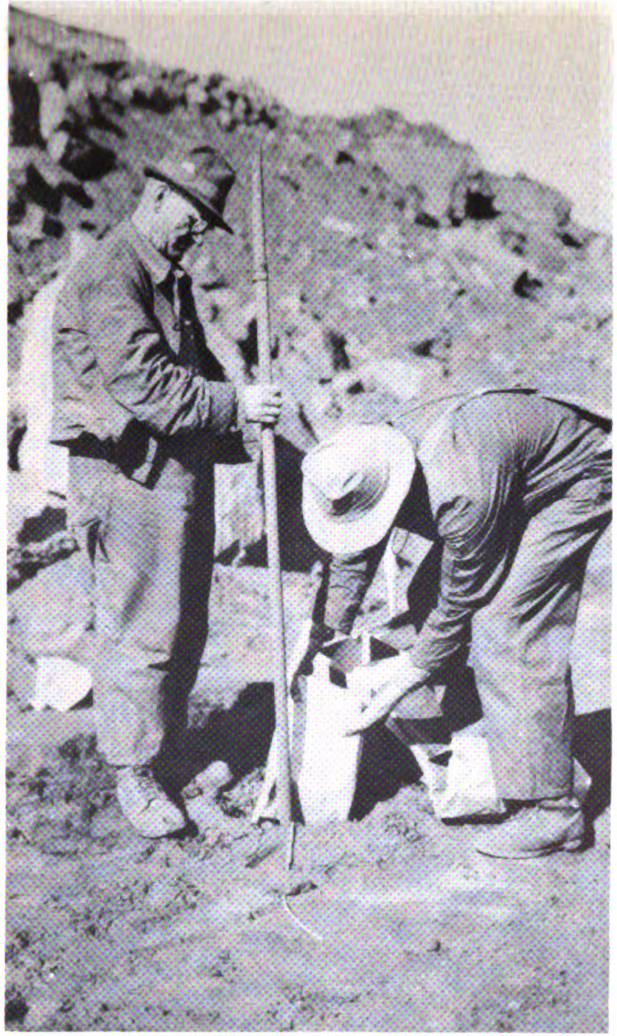


Figure 12. - Pouring free-running dynamite from bag into hole.

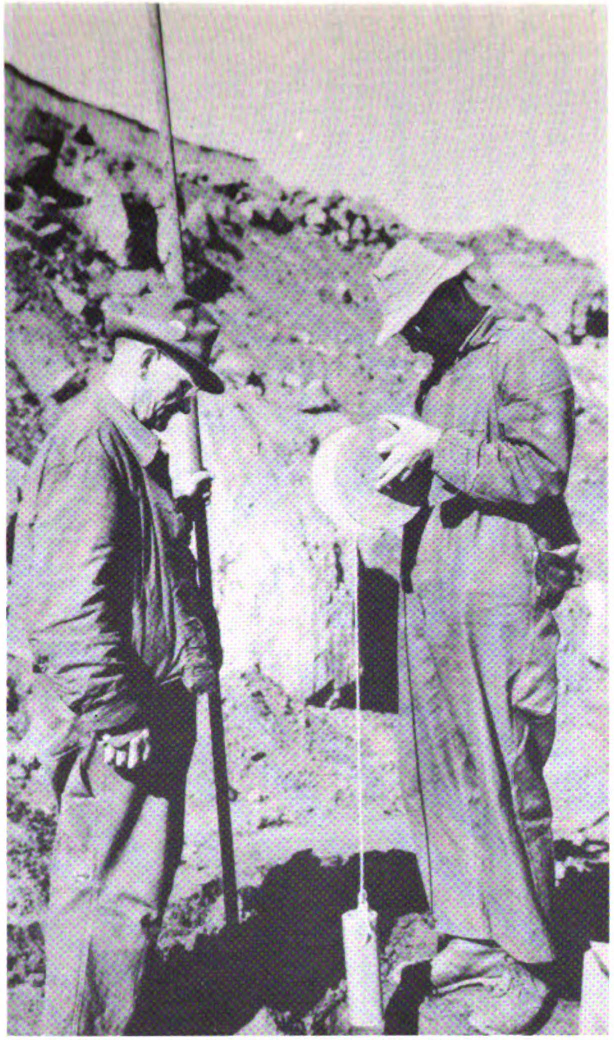


Figure 13. - Lowering primer with detonating fuse into hole.

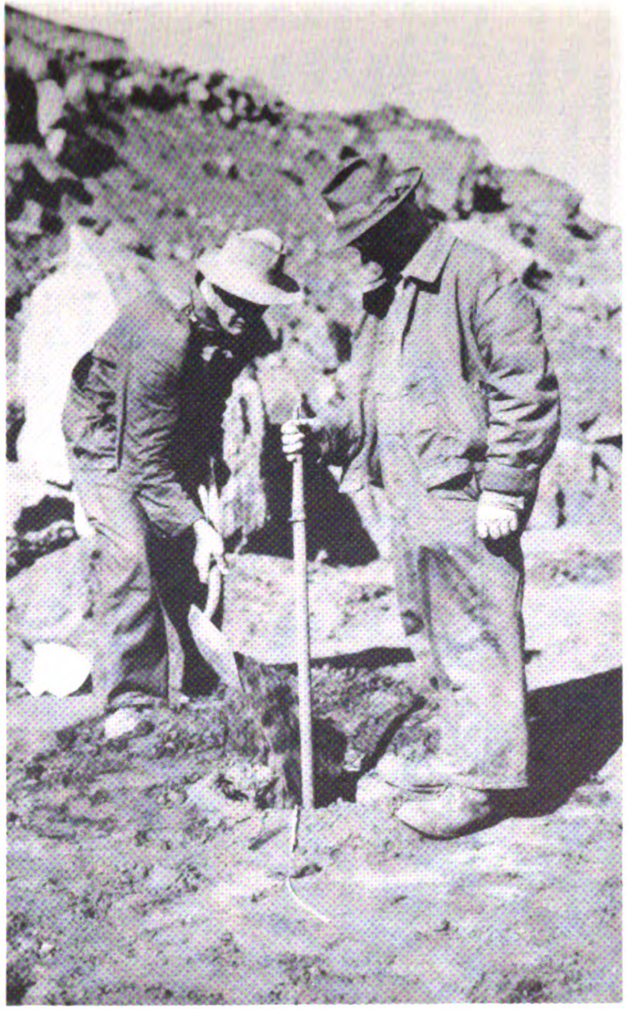


Figure 14. - Shoveling and tamping stemming material into hole.

Some blasters cut each cartridge in two or three pieces or slit the paper wrapper before dropping the explosive into the holes; others dropped the whole unslit cartridges. Free-flowing dynamite was poured into the holes (fig. 12), but at a few mines the unopened bags were dropped into them. At most mines, each cartridge of explosive was tamped as it was put into the hole; however, at some mines, the charges were not tamped, and at others the charges were tamped after every second or third cartridge. Primers were not tamped.

The general practice was to lower primers with detonating fuse into the holes with the fuse supporting the weight (fig. 13); however, at two of the mines, the primers with detonating fuse were dropped into the holes. Preference as to position of the primers was (1) at the bottom of the charge, 22 mines; (2) at the center of the charge, 6 mines; and (3) next to or at top of the charge, 3 mines. At one mine, two primers were used in holes 40 feet deep; one primer was placed three-fourths of the distance to the bottom of the charge, and the second was placed at the center of it.

When loading vertical holes, the detonating fuse was cut off about 3 feet above the collar of the hole, and the loose end was secured by (1) tying it to a piece of board, (2) tying it to a piece of rock or ore, or (3) placing a piece of rock or ore on top of it. At some mines the fuse was cut off immediately after the primer was lowered into the hole (which is the safest method), and at other mines it was cut off after the entire charge of dynamite was loaded in the hole and before the stemming material was inserted. Some blasters placed an empty explosives case or a piece of waxed paper from a case of explosives over the end of the detonating fuse to protect it from the weather.

Loading vertical churn-drill holes promptly after drilling to prevent holes from caving or becoming blocked was common practice. At many mines, holes were loaded within 20 to 50 feet of an operating churn drill, because the holes would not remain open more than an hour or two after they were completed. The consensus of mine operators was that this was not a dangerous practice when using detonating fuse, because no detonator was in contact with either the explosives or the fuse until immediately before the blast.

Quantity of Explosives Used

Iron ore in most open-cut mines was blasted primarily to loosen the material for the power shovels rather than to dislodge it entirely; consequently, loading the holes with heavy charges of explosives was not necessary. In the hard-ore mines, however, heavy charges were used.

Generally, the quantity of explosives to be used per hole was left to the judgment of the blaster, who learned from experience how much was necessary to loosen the ground for efficient shovel loading. At some mines, however, the burden on each hole was computed, and a predetermined factor (pounds of explosives per cubic yard of burden for the different types of material to be blasted) was used. The average quantity of material broken per pound of explosives was 2.5 cubic yards, which gave a factor of 0.4 pound of explosives per cubic yard of material in place. This factor ranged from 0.14 to 1.0 at various mines, depending on the type of material blasted. In table 4, the mines are divided into six groups, and the number of mines, the cubic yards of material broken, and the explosives factors are shown for each group.

TABLE 4. - Material broken per pound of explosives

Number of mines ..	12	10	5	2	2	1
Cubic yards broken per pound explosives	1-2	2-3	3-4	4-5	5-6	6-7
Explosives factor (pounds per cu. yd.)	0.50-1.0	0.33-0.50	0.25-0.33	0.20-0.25	0.17-0.20	0.14-0.17

Deck or Space Loading

Deck or space loading was observed at two mines. The deck-loading charge for a 42-foot hole in soft paint rock was: (1) four 5- by 16-inch cartridges of gelatin dynamite with detonating fuse attached to the first or bottom cartridge, (2) 14 feet of fine ore and gravel for stemming, (3) one 5- by 16-inch cartridge of ammonia dynamite with the fuse threaded diagonally through the cartridge, and (4) 22 feet of stemming material to the top of the hole.

Stemming

For stemming material, virtually all the mines used fine ore obtained at the blasting site. One of the following stemming materials was used at each mine: (1) the remains of ore samples from the laboratory, (2) fine ore and gravel, (3) sandy gravel, or (4) sand. The stemming material was shoveled into the holes, and in only a few instances was it tamped (fig. 14). The holes usually were stemmed to their collars; at most mines stemming occupied 50 to 80 percent of the depth of the hole. At one mine only 3 feet of stemming was inserted into the hole, 24 feet, or 60 percent, of the hole being left unstemmed. Neither the explosives nor the stemming were tamped at this mine.

Loading Horizontal Holes

Horizontal, auger-drilled, 6-inch holes were cleaned with the auger drill bits. The 3-1/4-inch holes that were drilled with cross-type bits were cleaned by blowing out with compressed air. Horizontal holes were not sprung before they were loaded with explosives.

The following explosives were used for loading 6-inch holes: (1) 5- by 24-inch cartridges of 40-percent semi-gelatin dynamite, (2) 5- by 16-inch

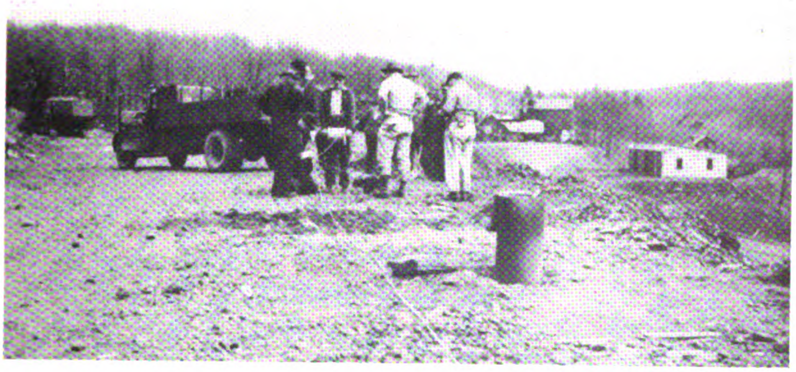


Figure 15. - Connecting 9-inch blast holes with detonating fuse.

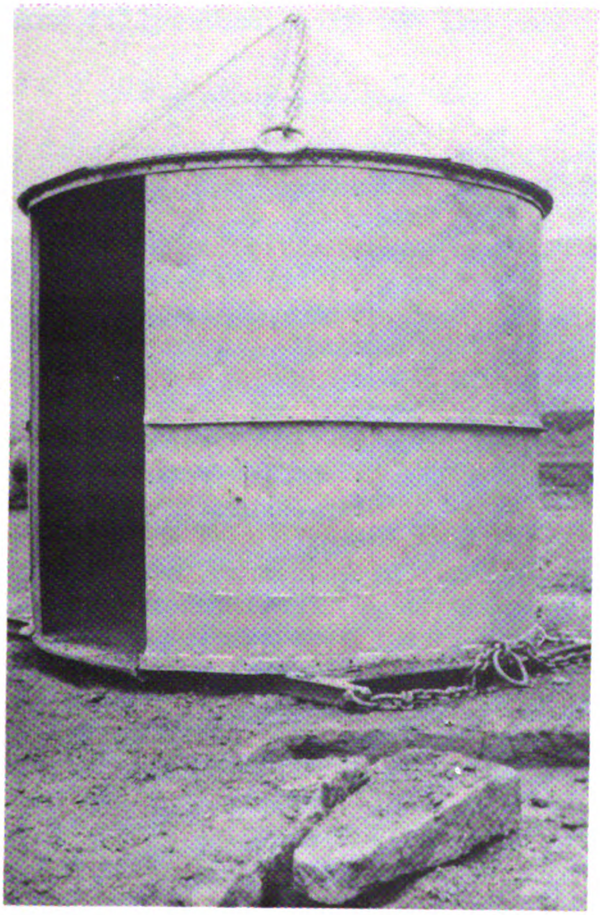


Figure 16. - Steel shelter house used in open-cut blasting.

cartridges of 60-percent semi-gelatin dynamite, and (3) 4- by 24-inch bags of 65-percent ammonia dynamite. The amount of material broken per pound of explosives ranged from 3.3 to 7.1 cubic yards, averaging 4.6 cubic yards at the three mines. The average explosives consumption was 0.22 pound per cubic yard of material in place. The primer cartridges were placed at the bottom of the holes at two of the mines and at the center of the charge at the third mine. Dynamite cartridges or bags were pushed into place and tamped separately. At two mines the tamping bar consisted of an 18-inch length of hardwood about 4 inches in diameter fastened to a 1/2-inch pipe that was provided in 5- and 10-foot sections.

At two of the mines wooden troughs of 1- by 4-inch boards 20 to 24 feet long were provided to facilitate loading the dynamite into rough holes. Fine ore in 4- by 16-inch paper bags was used as stemming material. All holes were stemmed to the collar, and the stemming filled about half the length of the holes.

The 3-1/4-inch holes were loaded with 2- by 12-inch cartridges of 40-percent strength semi-gelatin dynamite. Three to six cartridges of dynamite were used per hole, and the primer was placed at the bottom of the hole. Sand in paper bags was used as stemming material; holes were stemmed to the collar, and the stemming filled about half the length of the holes.

Connecting Blast Holes

Plain detonating fuse generally was used for trunk lines to connect several blast holes (fig. 15). The branch line of fuse from each drill hole was tied at right angles to the trunk line with a half hitch, so that the loose end did not point toward either the branch line or the trunk line. All connections were counted and inspected before attaching the detonator to the detonating fuse. Common practice was to secure the blasting cap or electric detonator to the end of the fuse with friction tape; however, at a few mines the detonator was attached with detonator leg wire. One blaster made the connection between the electric detonator and the detonating fuse by inserting the detonator into one end of a 1-1/8- by 8-inch cartridge of 60-percent gelatin dynamite and inserting the fuse into the opposite end of the cartridge.

When two rows of holes were connected to a single trunk line, the detonating fuse was laid along the front row of holes and looped back to lay along the back row of holes. The free end of the trunk line was then connected to the main part of the trunk line between the detonator and the first hole in the front row, thus forming a closed circuit and permitting the detonating wave to travel along both the front and back rows of holes simultaneously. Two or three parallel rows of holes frequently were blasted separately to reduce the violence of the blast. A trunk line was used for each row of holes, and electric detonators of the proper delays were used to detonate each row at desired intervals.

Duplex wire, 14- or 16-gage, generally was used for blasting lines between the electric detonators and the power circuit or blasting machine; however, at a few mines, No. 20 copper-connecting wire was used as the blasting line. Blasting lines ranged in length from 100 to 600 feet; 250- and 300-foot lengths were used most commonly, but lengths less than 200 feet were used at seven mines. The general practice was to keep the ends of the blasting lines shunted until they were connected to the source of power; but a few blasters did not do so. At seven mines the completed blasting circuits were tested with a galvanometer before connecting the blasting line to the source of power. to insure that the circuit was continuous and in proper condition for firing. Blasting circuits were not tested at the other mines.

Several sources of electric current were used for primary blasting; in order of use they were (1) 50-shot push-down type blasting machines at 14 mines, (2) 10-shot twist-type blasting machines at 9 mines, (3) 440-volt alternating current through a square-D switch on the rear of the churn-drill rigs at 2 mines, (4) 32-volt alternating current through a square-D switch on the rear of the churn-drill rig at 1 mine, and (5) two 1-1/2-volt dry-cell batteries connected in series at 1 mine.

Millisecond Timing

Although they were not in general use in the open-cut iron-ore mines of the Lake Superior district, two recent developments in electric delay blasting equipment are worthy of mention. Explosives manufacturers 8/ have developed fast-delay or millisecond-electric blasting caps that fire individually but in such small difference in time relation to each other that the action of certain charges supplements the action of other charges before there has been any appreciable movement of the burden or release of gases from behind the burden.

One explosives company is manufacturing a blasting timing device for millisecond timing of the detonation of instantaneous electric blasting caps. The timer is an electrically operated device so constructed that by selection of one of several interchangeable gears, one of four delay intervals ranging from 10 to 25 milliseconds in 5-millisecond increments can be obtained between detonations of 15 different blasting circuits, each of which contains one or more instantaneous electric blasting caps. For any particular gear, only one of the four delay intervals elapses between detonation of successive circuits.

Guarding and Warning

Blasting areas for daily routine blasts of 5 to 20 holes in soft ore were guarded by the blaster's helper and the drill crew assisted by the shovel crew and the foreman when necessary. Most blasting was done on shift, and as a general rule the blaster was in charge. At several mines where blasting was done at lunch time or at the end of the shift, a foreman and the blasting crew, assisted by the drill and shovel crews, as necessary, guarded the area and the roads into the mine.

8/ McFarland, D. M., Better Fragmentation Claimed for Fast-Delay Caps: Min. and Met., Dec. 1948, pp. 660-662.

Several methods were used to warn the men in the pit to seek shelter when a blast was to be set off. These methods, in order of use, were (1) vocal warning to all men by the blasting crew, drill crew, and foreman; (2) a series of blasts from a whistle or siren on a power shovel; (3) a series of blasts from a whistle on a locomotive; (4) a series of blasts from a whistle or siren at the truck-dumping station; and (5) the use of a police whistle by the blaster to attract the attention of the men. Following a warning, the blaster ascertained that all work was stopped and that all men and equipment were in the "clear"; he then shouted "fire" and, after a few seconds, detonated the blast.

Many of the mining companies provided portable steel shelter houses to protect the men from flying material during blasting. The shelter houses were mounted on skids (fig. 16), so that they could be moved readily by truck or tractor to a site within reach of the blasting line. At a few mines, the blasters set off the shots while standing in the open 150 to 500 feet away from the blast holes; others set off the blasts from the shelter of churn-drill rigs or power shovels 100 to 300 feet from the blast holes.

Missed Holes

At about half the mines visited, the blasters reported that no holes had misfired since the use of detonating fuse was instituted; this period of immunity was estimated to be from 4 to 7 years at the different mines. The common practice at mines where misfires occurred was for the blaster to report the misfires to the pit foreman or, at larger mines, to the blasting foreman. Generally, misfires were discovered by visual inspection of the area after a blast was completed.

The procedure for handling missed holes differed from mine to mine, and at one mine no definite procedure was followed. The various methods for handling missed holes, in order of use, were (1) drilling a new hole 3 to 5 feet away from the missed hole and blasting the new one; (2) blowing out the stemming material with compressed air, using 6-foot sections of 2-inch pipe as a casing; leaving the casing in the hole and inserting a new primer, which was fired electrically; (3) removing the stemming with an auger to a safe distance from the dynamite and proceeding to open the hole to the dynamite with a sharp wooden pole, then inserting a new primer, and firing electrically; and (4) making a hole through the stemming material with a sharp wooden pole, then inserting a new primer, and firing electrically.

At two mines that used a blasting agent in metal cans, the charge in a missed hole was dug out of the broken ore with the power shovel. At another mine using a blasting agent, the stemming in a missed hole was removed with an auger, then a new primer was inserted in the hole and fired.

Secondary Blasting

Secondary blasting was not required at most mines but was necessary occasionally at others. Large chunks were block-holed at 6 mines, and adobe blasting or mud-capping was practiced at 10 mines.

Block-Holing

Either Diesel- or gasoline-motor-driven portable air compressors provided power for the hand-held pneumatic drills. Drill bits ranged in diameter from 1-1/8 to 2-1/4 inches, and holes were drilled 10 inches to 2 feet in depth, depending on the size of the chunks to be broken.

Generally, 40-percent ammonia dynamite or 60-percent semi-gelatin dynamite in 7/8- by 8-inch to 1-1/4- by 8-inch cartridges was used for block-holing large chunks; one-half to two cartridges were inserted in each hole. At times, as many as 50 large chunks were blasted simultaneously. The general practice was to connect the separate charges to a detonating-fuse trunk line and detonate the fuse with a single electric detonator. When the chunks were too close together, or when the blockholes were shallow, each charge was primed with an instantaneous electric detonator, and the group of shots was connected in a series circuit and then fired.

Mud-Capping

Large chunks were broken by mud-capping at a few mines during the summer or mining season, and at other mines during the winter or stripping season. Mud-cap charges ranged in size from half a pound (one 1-1/4- by 8-inch cartridge) to 50 pounds of dynamite, depending on the size of the chunk. Charges were detonated by (1) cap and fuse, or (2) detonating fuse.

When using cap and fuse, as many as 10 shots were blasted at one time. The blaster used a 2-foot notched fuse as a lighter and a timer.

From 4 to 15 chunks were blasted at one time when using detonating fuse. The detonating fuse trunk line was laid alongside or between the dynamite cartridges and strung from one chunk to another, and the detonating fuse was detonated by cap and fuse or by an electric detonator.

COYOTE-HOLE BLASTING

At one of the mines, taconite islands left from earlier mining operations were found to be underlain by merchantable ore. It was decided to mine the ore under one of these islands, and this necessitated blasting a section of rock 150 feet long, 100 feet wide at the summit, and 70 to 80 feet high (fig. 17). A repair shop building, a large butane fuel tank, and an electric power line were 245, 230, and 125 feet, respectively, from the island.

Inasmuch as drilling vertical holes from the top of the island was not feasible because of the difficulties in getting suitable drilling equipment on the island and the danger of flying rock from blasting vertical holes, a coyote-hole blast from within the island was planned. A dog drift was driven in the soft ore under the rock capping on the northeast corner of the island to the approximate midpoint; the drift was turned along the long axis of the island, and stub drifts were driven at right angles to the main drift to extend under the different "butte" projections of rock.

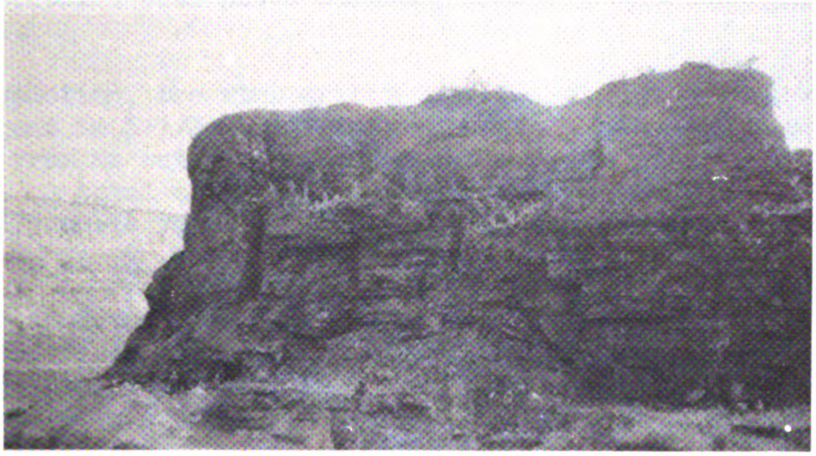


Figure 17. - North side of taconite island before blasting. Note adit entrance at bottom left.

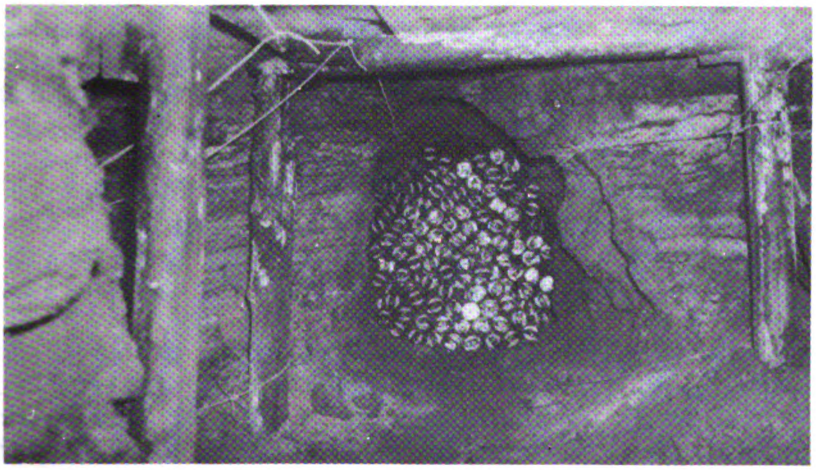


Figure 18. - Charge of blasting agent in dog drift for coyote-hole blast, showing detonating fuse connections from similar charge in stub drift at left.

Two miners drove a 3-1/2- by 5-foot dog drift in 5-foot stages, using 7/8-inch hexagonal drill steel and four-point detachable bits having both center and side holes. Three lengths of drill rods were used for each 5-foot hole, and 2-, 1-3/4-, and 1-1/2-inch diameter bits were used in each hole. Five holes were drilled and blasted per round. Each hole was loaded with five or six 7/8- by 8-inch cartridges of 40-percent ammonia dynamite. Primers were prepared with No. 6 blasting caps and 40-second safety fuse in 6-foot lengths.

After completion, the stub drifts were loaded with 9 separate charges of blasting agent in 5-1/2- by 24-inch metal cans (fig. 18). The charges were computed from an estimate based on the engineer's map and cross sections of the island. A total of 32,021 pounds of explosives was used for an estimated 52,675 cubic yards of rock or 0.608 pound of explosives per cubic yard of rock.

Two loops of detonating fuse were strung in the stub drifts, one along the sides of the floor and one suspended along the sides of the back on nails driven in cracks and soft ore. The loops ended at the stub-drift entrances at the main drift.

Cans of blasting agent (5 at a time) were brought in on wheelbarrows, care being taken not to puncture the cans when handling them. The cans were laid flat at the end of the stub drift in two rows of tiers butted together, insuring maximum contact between cans. The cans were placed so as not to jam or pinch the detonating fuse.

One primer can was placed in the third or fourth tier from the top or the third or fourth tier from the bottom in each row of tiers, separated horizontally from each other so that the ends of the primer cans were not butted together. One branch connection ran from each detonating-fuse loop at the top of the drift, crossing to the opposite loops of detonating fuse at the bottom of the drift. One branch line ran through the fluted tube on one primer can, and the opposite branch line ran through the fluted tube on the second primer can, thus providing separate connections to the main loops for two primer cans at different points in the charge.

The farthest charges were placed first, then the detonating fuse connecting loops were strung retreating toward the entrance. All bottom loops were covered with fine dirt and cardboard to protect them from falling rock. The main trunk lines in the centerline drift were cross-connected. In the entrance drift, the main trunk lines were tied together and strung through two pipe lines on each side of the floor and extended to the outside.

A bulkhead was erected in the entrance drift 6 feet from the centerline drift, and, from the bulkhead, 50 feet of the entrance drift toward the portal was filled with broken material for stemming. About 5,500 cubic feet of air space remained between the blasting agent charges and the stemming.

The exterior ends of the detonating fuse were tied in T-connections to a single lead, and a No. 6 blasting cap, crimped to a 10-foot length of 40-second fuse, was taped to the single lead.

DRILLING AND BLASTING FROZEN GROUND

During the winter months frost penetrates the overburden to a depth of 6 to 8 feet, depending on the severity of the winter. At most of the mines, overburden is stripped in the winter, and the frozen ground must be drilled and blasted before it can be removed by shovel or dragline.

A few mines were visited during the latter part of January and the early part of February 1948 to observe drilling and blasting practices in frozen material. The general procedure at one mine was as follows:

Three rows of 6-inch, vertical, churn-drill holes were put down to a depth of 30 feet in material consisting of gravel, boulders, and clay in which frost had penetrated to a depth of 6 to 8 feet. The holes were drilled 12 to 14 feet apart; the first row was 5 to 12 feet from the crest of a 25-foot bank, and the intervals between the first and second and the second and third rows were 12 to 14 feet. The rate of drilling ranged from 100 to 150 feet per 8-hour shift. Holes were loaded as soon as the churn drill had been moved ahead to start the next hole.

Semi-gelatin dynamite, 60-percent strength, in 5- by 24-inch cartridges, and 65-percent ammonia dynamite in 4- by 24-inch bags were used for blasting. Each hole in the first row was loaded with (1) four cartridges of semi-gelatin dynamite as the bottom of the hole, with the detonating fuse attached to the bottom cartridge, (2) 16 feet of stemming, (3) two cartridges of semi-gelatin dynamite, with the fuse laced through one of the cartridges, and (4) 5 feet of stemming to the collar of the hole.

Each hole in the second and third rows was loaded with (1) one cartridge of semi-gelatin dynamite with detonating fuse attached, (2) four bags of ammonia dynamite, (3) 15 feet of stemming, (4) one cartridge of semi-gelatin dynamite, with the fuse laced through the cartridge, and (5) 5 feet of stemming to the collar of the hole. Neither the dynamite nor the stemming was tamped in the holes.

The three rows of holes were blasted simultaneously. A No. 6 instantaneous electric detonator was connected to the end of the detonating fuse trunk line and detonated by a 10-shot twist-type blasting machine. Blasts were set off at noon or at the end of the shift when all men had left the area.

COMMENDABLE PRACTICES

The following commendable drilling and blasting practices were observed at one or more mines.

Drilling

1. Drills were stopped when oiled or repaired.

2. Two-foot square covers of 2- by 4-inch lumber covered with galvanized iron or heavy wire mesh were used to cover completed vertical holes after drilling and prior to loading.

3. Drills were frame-grounded by use of four-conductor electric cables.

4. Bell guides of churn drills were attached to the mast by a safety chain.

5. Drillers and helpers wore hard-toed shoes.

6. Trucks and railroad cars for servicing drills were equipped with hoists for handling heavy equipment and supplies.

7. Late-model drills were equipped with a new-type tool wrench, eliminating the use of heavy hand wrenches and chain tongs when changing bits.

8. Mechanisms of churn drills were guarded by heavy wire-mesh enclosures, each of which had a contact shut-off switch attached to the door.

Blasting

1. After loading a vertical blast hole, most blasters tied the end of the detonating fuse to a piece of wood supported over the hole on two chunks of ore or rock. One blaster also attached a piece of waxed paper to the end of the detonating fuse to protect it from the weather.

2. Specially constructed railroad-car magazines were used for transporting explosives from the surface into the open pits.

3. At one mine a specially constructed panel truck with doors on one side and the rear was used to deliver explosives to blasting sites.

4. At one group of mines, a general drilling and blasting foreman was in charge of all drilling and blasting operations and equipment.

5. Steel shelter houses were used at many mines for protection when blasting. Shelter houses were moved as needed to be near the blasting lines.

6. At most mines all blasting was done electrically.

7. Blasting at some mines was done only at change of shifts, when all men were out of the pit.

8. Many blasters took exceptional precautions in clearing persons from the area before a blast was detonated. They had the assistance of foremen, shovel crews, and drill crews and did not initiate the blast until all persons were out of the danger zone.

9. "No Smoking" rules in the vicinity of explosives were observed strictly at most mines.

10. At most mines, after charging drill holes the unused explosives were returned to the magazine.

11. Many blasters tested the electrical blasting circuit with a galvanometer before blasting.

12. As a general practice, all large charges of explosives were loaded under the supervision of the foreman or engineer in charge of the work.

13. Detonating fuse for blasting was used at 31 of the 32 mines visited.

UNSAFE PRACTICES

Generally, unsafe practices and conditions are corrected by the foremen and supervisors as soon as they are detected. The following unsafe practices were observed during this study, but many of these were observed at only one mine.

Drilling

1. The driller and helper on a horizontal drill were drilling at the toe of a 30-foot bank and were not wearing hard hats and small pieces of earth were dropping near them.

2. A drill operator kept too many drill bits on the churn drill platform, causing a stumbling hazard.

3. The clutch and drive chains on some churn drills were not guarded.

Blasting

1. Explosives were hauled into the pit on a water-tank truck, and explosives cases were in contact with exposed metal.

2. Holes loaded with dynamite were not fired until two days after charging.

3. Capped fuses, only 1-1/2 feet long, were inserted into cartridges of dynamite, lit, and dropped into vertical holes when springing holes.

4. Empty dynamite cartons and paper were burned 30 feet from holes loaded with dynamite.

5. A blaster used a short fuse, 2 feet long, to set off a detonating fuse trunk line when blasting a group of vertical holes.

6. A blaster was smoking a cigarette while sitting on a pile of six cases of dynamite.

7. A blast of thirteen 34-foot horizontal holes was set off before a churn-drill crew about 500 feet away got under cover; the drill helper was injured slightly by flying material.

8. Explosives were hauled from the storage magazine into the pit on the tender of a steam locomotive.

9. Three electric detonators for "unblocking" holes at a churn drill were lying unprotected on a rock pile nearby.

10. Large quantities of dynamite were left in the open at a drilling site for several days.

11. A dull churn-drill bit was carried in the box of a pick-up truck with four cases of dynamite.

12. At a few mines, the blasting cables were too short. The blaster set off the shots while in the open, and was exposed to flying material.

13. Cases of dynamite were in contact with exposed metal in the bodies of trucks during transportation from the magazine to the blasting site.

14. Explosives were piled too near haulage tracks and operating churn drills.

15. At a few mines, the detonating fuse was not cut off from the spool after the primer had been lowered into the hole, but it was left attached to the spool until all dynamite had been placed in the hole. If the dynamite in the hole had been detonated accidentally, the spool of detonating fuse on the surface probably would have been detonated, as would other dynamite in the vicinity.

16. At one mine, two 1-1/2-volt dry-cell batteries connected in series supplied the electric energy for firing; but the batteries may not be powerful enough under all conditions, and their use should be discontinued.

SUGGESTED SAFETY PRACTICES

At a meeting of the Itasca County Mines Safety Council at Coleraine, Minn., May 27, 1948, the following list of safe practices was adopted:

Guide for Safe Practices for

Churn Drills

Vertical Rotary Drills

Horizontal Auger Drills

By

The Itasca County Mines Safety Council

It is the intention of the council to make the list of suggestions available to any iron-ore mining company for the purpose of formulating their own guide for safe practices, book of rules, or safety code. Such companies can use their own discretion as to which safety suggestion they wish to adopt, modify, or eliminate. They can add other suggestions or use their own phraseology; briefly this list can be used as a guide to formulate and compile their own code of safe practices for their own employees or supervisors.

1. Drillers are responsible for their helpers and the safe and efficient performance of their duties.

2. Drillers are responsible for their helpers while moving their machine. In no case shall the drill machine be moved without the helper, and the helper should be within sight of the driller at all times.

3. It is the driller's responsibility to instruct helpers on starting and stopping machine.

4. It is the helper's responsibility to know how to start and stop machine.

5. The drill and its surrounding area must be kept orderly at all times. (Tripping hazards, ice, etc.)

6. No one but qualified electricians are permitted to make any electrical repairs on the machine.

7. No one is allowed on mast of drill while drill is operating.

8. No one is allowed on mast at any time unless he is wearing a safety belt. Wear protective equipment provided for your safety. (Goggles, belts, hard hats, etc.)

9. When necessary to work under the spudding beam of a drill, the beam must be securely blocked with timber in its uppermost position, or otherwise held by locking device if so provided.

10. Under no circumstances will a person be allowed in the machine when the motor is running.

11. If hole location is such that the drill operator feels it is unsafe, he will immediately contact his foreman.

12. Keep all explosives locked at all times.

13. When drillers blast electrically, they should keep battery ends of lead wires shunted (twisted together) until ready to connect to the battery. (Disconnect wires from battery immediately after blasting, and shunt lead wires.)

14. Do not oil, grease or repair machine while machinery is in motion. (Cut out main switch on electrically operated drills.) Shut off motor on gasoline- or Diesel-powered drills.

15. Cover each drill hole immediately upon completion.

16. Be cautious when drilling or propelling in the vicinity of high-voltage lines. (Keep a safe distance from such lines - 25 or more feet.)

17. All drill masts must be inspected and greased daily by the drill runner. (This applies particularly to parts on the mast, including the shock-absorber pin.)

18. When drill bit or sand bucket is caught or wedged in a hole, extreme care must be observed when removing them. (Notify your foreman.)

19. The sand bucket must not be guided by hand. Regular tools for this purpose must be used.

20. Guards that are installed on drills must not be removed, except if required to do the necessary repairs and adjustments. (See 10-14) Replace guards before starting machinery.

21. If the cable becomes crossed on the drum, the operator should make sure stem is either on the bottom of the hole or out of the hole laid on the ground horizontally before trying to straighten the cable.

22. Men should not work under suspended tools. When collaring holes, inspecting, or any operation where the tools are out of the hole, they should be lowered to the ground.

23. Drill crews should inspect the face of the banks carefully before drilling operations begin. All loose boulders and material should be removed. Report such unsafe condition to the immediate foreman.

24. Churn-horizontal-auger- and vertical-rotary-drill operator or his helper should be at the controls when the drill is in operation.

25. Employees should keep in the clear of the augers or drill stems while they are in motion and not pass under or step over a moving stem or auger. Keep hands off of a revolving auger.

26. The driller should not attempt to operate the horizontal drill when alone.

27. Properly and safely handle the electric cable (if not instructed, see your foreman).

The following safety suggestions primarily concern the management:

1. When drilling with drill platform over edge or crest of bank, the platform should be provided with a guard rail or cable to prevent the driller and/or helper from stepping off.

2. All drills should be provided with a shelter house having a metal roof.

3. A metal shield should be provided on the left side of the drill machine, to protect the driller or helper when operating the slush bucket.

4. Ladders, for safer climbing, should be provided on the back-braces.

5. Provide adequate lighting on and about drills.

6. Safely guard all drills.

7. Old or inexperienced men should not be assigned for work on or about a churn, vertical-rotary, or horizontal auger-type drill.

ADDITIONAL SUGGESTED SAFETY PRACTICES

As a general rule, each case of explosives contains a list of instructions and rules for the safe use of explosives as recommended by the Institute of Makers of Explosives. Supervisors should insist that all persons who handle explosives be familiar with and follow these instructions and rules. It is unnecessary to repeat these instructions and rules in this circular; however, the following suggested safety practices[9] probably will assist in eliminating some of the observed unsafe practices.

1. Detonators, tools, and materials other than explosives should not be stored in an explosives magazine; however, this does not prevent storing safety fuse or detonating fuse in any explosives or detonator magazine.

2. Vehicles used for surface transportation of explosives should be constructed substantially, have tight bodies with no internally exposed sparking metal, and should be maintained in good working order. Open vehicles should be provided with tarpaulins. The ends and sides of the vehicles should be high enough to prevent containers from falling off.

3. Vehicles carrying explosives should not carry metal, metal tools, oils, matches, firearms, acids, or flammable materials of any description. This does not apply to truck repair tools carried in a proper receptacle.

4. Explosives or detonators should never be left unattended until after they are in a securely locked magazine.

5. Blasting crews should be organized carefully, and each man should be assigned to specific tasks to prevent confusion.

6. Smoking should be prohibited while handling explosives.

7. Paper and empty explosives containers should not be burned in the vicinity of a blasting site until all explosives have been removed from the area and the loaded holes have been blasted.

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[9] Bureau of Mines, Some Safety Practices for Metal Mines, Nonmetal Mines (Other Than Coal), Mills, Metallurgical Plants, and Quarries: Inf. Circ. 7387, Sept. 1946, 56 pp.

8. Only wooden tamping bars with no exposed metal should be used, and tamping should be done by pressure on the bar. Do not "ram" the tamping bar. Metal tamping bars should not be used.

9. All approaches to the vicinity of the blasting area should be guarded by responsible employees to prevent anyone from walking into danger unknowingly.

10. Distinctive signals should be provided to give adequate warning before a blast. The "all clear" signal should be given when it is safe to return.

11. The minimum length of fuse should be designated by the company management but should never be less than 30 inches.

12. The burning rate of fuse should be tested frequently and should be posted for the benefit of all concerned.

13. Lighting of fuse before placing the primer in a drill hole should be strictly prohibited.

14. The leg wires of detonators should be kept shunted until ready to connect to the blasting circuit.

15. Lead wires should be protected from all possible sources of electricity, including stray currents. The ends of the lead wires should be kept shunted until ready to connect to the blasting circuit.

16. Blasting lines of duplex wire, because of possibility of short-circuits resulting from inferior or broken insulation, are not suitable for firing more than one detonator at a time. In multiple blasting, it is recommended that two lines of single solid wire be used.

17. Stranded-lead wires should not be used because single strands inside the insulation are difficult to detect.

18. No. 20 copper connecting wire should not be used for lead wires. Such wire is too small to carry the current for blasting, and the insulation will not insure against excessive current leakage, particularly under wet conditions.

19. Blasting lines should be long enough to permit the blaster to set off the blast from a safe shelter.

20. Holes should never be loaded while a locomotive, shovel, or other coal-burning equipment is working in the vicinity.

21. Stemming should be placed in a hole immediately after loading explosives into it; care should be observed to protect the detonating fuse or lead wires from damage.

22. When the blasting signal is given, men should seek shelter immediately at a safe distance and under a suitable roof constructed of at least 2-inch oak boards. Men should remain under the shelter until the signal has been given that blasting has been completed.

23. Drill holes that have been sprung or chambered should be allowed to cool before explosives are loaded into them.

ACCIDENT STATISTICS

Drilling and blasting injuries during the 4-year period 1944-47 at the open-cut iron-ore mines in the Lake Superior district are listed by causes in table 5.

Drilling accidents caused 63 lost-time injuries, including 2 fatal and 6 permanent-partial injuries. This was about 8 percent of all open-cut injuries during the 4-year period. The first four causes listed in table 5 accounted for 39 (62 percent) of the drilling injuries.

One fatality was caused when a drill helper was thrown from the ground to the drill platform by the drill cable. A drill bit stuck in a vertical hole, cleared itself, and tightened up on the slack cable lying on the ground when the bit dropped to the bottom of the hole. The helper had been assisting in straightening out the slack cable and probably his foot was caught in a coil of the cable.

The second fatality was caused when a drill helper placed his left hand on a moving auger bit of a vertical drill. The glove on his hand caught in the notch at a bit joint, and he was twisted around the bit. He died about a month later from his injuries.

Blasting accounted for five lost-time injuries during the 4-year period. Men were struck by flying material from blasts in all five accidents.

Table 6 is a summary showing the accident experience of all open-cut iron-ore mines including the beneficiation plants in the Lake Superior district for the 8-years 1940-47, inclusive, and the average for the 8-year period. Both frequency and severity rates show an improvement in 1947 over the 5 preceeding years, and both are below the 8-year average.

SUMMARY

Drilling and blasting practices were observed at 32 open-cut iron-ore mines in the Lake Superior district. With a few exceptions, blast holes were drilled with standard caterpillar-mounted churn drills. Seventy-seven percent of the churn drills were operated by 440-volt alternating-current motors, and 23 percent were operated by gasoline-powered engines. Six-inch chisel-type bits generally were used for drilling holes in ore, but at several mines 9-inch bits were used for drilling holes in hard ore and rock.

Generally, the moving machinery on the drills was well-guarded; many mining companies installed additional guards on new drills before placing them in operation.

TABLE 5. - Drilling and blasting injuries, 1944-47, Lake Superior district open-cut iron-ore mines

Cause of injury	Number of injuries	Total days lost
Drilling:		
Hit on foot or leg by drill bit, bailer, casing, tools, etc.	18	692
Hurt while changing churn drill bits	8	902
Lifting heavy objects, drill bits, etc.	7	192
Hit or caught by tool cable or bailer cable	6	6,429
Caught by moving drill bit or auger	4	6,103
Hand caught between drill stem and casing	4	1,279
Slipped, fell, or jumped from drill	3	147
Hit in eyes by flying material, not using goggles	2	1,841
Caught in driving machinery of drill	2	289
Fingers hit by drill hammer, bailer, etc.	2	148
Hit by material falling from drill mast	2	67
Hit by drill spudding beam	2	42
Caught between drill mast and drill stem guide	1	70
Stepped into open churn-drill hole	1	43
Hit by drill-mast crank	1	7
Total drilling	1/ 63	18,251
Blasting:		
Hit by flying material	5	303
Grand total, drilling and blasting	68	18,554

1/ Includes two fatal and six permanent partial injuries.

TABLE 6. - Accident experience at open-cut mines and beneficiation plants, Lake Superior district, 1940-47 1/

Year	Number of mines and plants	Man-hours worked	Number of injuries	Days lost	Frequency rate per million man hours	Severity rate per thousand man hours
1940	38	8,869,185	61	23,486	6.88	2.65
1941	61	14,007,215	120	51,315	8.56	3.66
1942	79	16,606,290	181	100,119	10.89	6.03
1943	76	20,916,864	310	95,949	14.82	4.59
1944	67	16,770,414	235	34,414	14.01	2.05
1945	67	16,809,051	188	70,568	11.18	4.20
1946 2/	69	13,280,957	186	42,173	13.25	3.18
1947 2/	81	17,801,587	195	36,533	10.95	2.05
Average		15,632,696	185	56,820	11.83	3.63

1/ Strome, John H., Review of Accidents in the Lake Superior District: Lake Superior Mines Safety Council 1948 proceedings, p. 38.

2/ Figures for 1946 and 1947 are for open-cut mines only, as beneficiation plants were reported separately.

Depth of holes drilled varied with the height of the bench, and, as a general rule, the benches were maintained at a height that could be trimmed with the dipper of the power shovel. Holes ranged in depth from 10 to 60 feet, averaging 30 feet.

Three types of high explosives and a blasting agent were used; in order of use they were (1) semi-gelatin dynamite, (2) ammonia dynamite, (3) gelatin dynamite, and (4) a blasting agent packed in metal cans.

Detonating fuse was used at 31 of the 32 mines visited. The almost universal use of detonating fuse for primary blasting in the open-cut iron-ore mines in the Lake Superior district is one of the outstanding safety practices adopted in recent years. Safety fuse and blasting caps were used at only a few mines for setting off the detonating fuse and in secondary or miscellaneous blasting.

Accident statistics for the district covering the 8-year period 1940-47, show that drilling accidents caused 63 lost-time injuries, including 2 fatal and 6 permanent-partial injuries. This was about 8 percent of all open-cut injuries in the district during the 4-year period 1944-47.

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